THE LOW TEMPERATURE MICROGRAVITY PHYSICS EXPERIEMNTS FACILITY

Talso Chui, Arvid Croonquist, Melora Larson, Feng-Chuan Liu, Warren Holmes,
Don Langford and John Pensinger
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 9110.

Abstract

The Low Temperature Microgravity Physics Experiments Facility (LTMPEF) currently in the design phase is a multiple user and multiple flight facility intended to provide a long duration low temperature environment onboard the International Space Station. The Facility will provide a unique platform for scientific investigations requiring both low temperature and microgravity conditions. It will be attached as a payload of the Japanese Experiment Module Exposed Facility (JEM-EF) and can house two science instruments each flight. The Facility consists of a 180-liter superfluid helium dewar and electronics to measure and control temperatures, including DC SQUID magnetometers for reading magnetic-salt based high-resolution thermometers. The facility will be launched full of cryogen, and retrieved when the cryogen is depleted. Industrial partners are responsible for building the facility, the electronics and part of the instruments. Principal Investigators from universities and other institutions are contracted to develop a major parts of the science instrument package. Detailed technical capabilities of the facility will be presented in this paper.

Introduction

The Low Temperature Microgravity Physics Experiments (LTMPE) project is the next step in a series of three very successful space flight low temperature experiments – The Superfluid Helium Experiment (1985), the Lambda Point Experiment[1] (1992), and the Confined Helium Experiment[2] (1997). This series of experiments have proven that very high-resolution experimentation can be implemented in the hostile environment of Space. For example, it was shown that temperature can be measured to better than 0.1 nano Kelvin in Space using Superconducting Quantum Interference Device (SQUID) magnetometer[2]. These high-resolution capabilities, which require operating at low temperatures, when combined with the microgravity condition in Space, open the door to many exciting new investigations with the potential of making breakthrough findings. The LTMPEF is designed to broaden investigation opportunities requiring these high-resolution capabilities in Space. Already, there are six investigations planned for the first two flights. To meet the demands of the science community, the Jet Propulsion Laboratory has partnered with Ball Aerospace and Technologies Corporation (BATC) to build the dewar and the facility enclosure. Design-Net Engineering has been selected to build the electronics and software, and Swales Aerospace has been selected to help build the instrument thermal mechanical structure. In the following, we will describe the design and the capabilities of the facility.

System Design and Capabilities

Figure 1 below shows the LTMPEF. It consists of the dewar, the electronics, the radiators, the science instruments which mount inside the dewar, and the facility enclosure that houses the dewar, the electronics and various interface components. These interface components will be provided to LTMPEF by NASA and NASDA. They consist of the Grapple Fixture for the JEM robotic arm to hold onto; the Flight Releasable Attachment Module (FRAM) for attaching to the launch carrier and the ISS robotic arm, and the Payload Interface Unit (PIU) for attaching to the JEM-EF and accessing the 120 V DC electrical power and the communication interfaces.

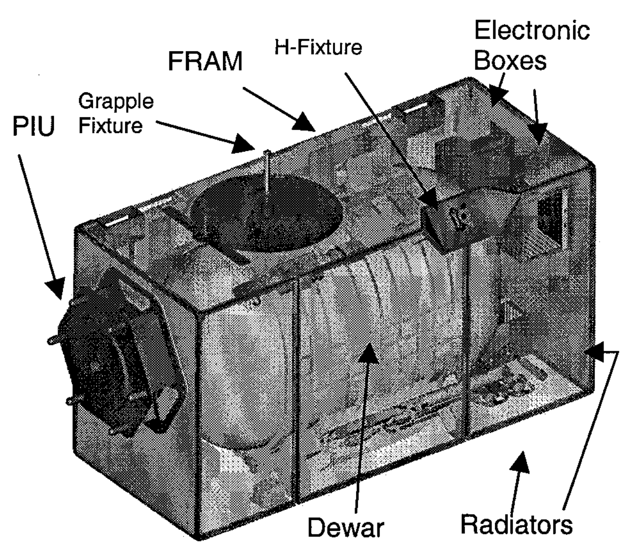

Figure 1: LTMPEF overview.

The space station robotic arm also interfaces with the H-Fixture for transferring the payload to and from the Shuttle. The maximum power available to the electronics during the mission is limited by the ability of the radiators to reject heat of about 235 W. Uplink low rate commands of no more than 864 bits/sec. are provided for the payload through a 1553B interface, and the high-speed downlink telemetry for the data is capable of handling 1.5 Mbps using Ethernet. Total mass of the facility is limited to 600 Kg and the envelope size is 1.85 m by 0.816 m by 1.037 m.

Dewar Design and Capabilites

The dewar contains approximately 180 liters of liquid helium and is expected to last about 4.5 months on orbit. The cross section is not cylindrical, but oblong in shape to maximize the use of the available volume within the defined envelope. This large volume also helps the dewar to stay below the superfluid transition temperature, without active evacuation, for 112 hours prior to launch, so that full science time can be achieved if launched within the first 2 attempts. If launched at the third and later attempts the on-orbit science time will be reduced. The dewar is designed to operate at a base temperature of 1.6K but is capable of raising its temperature to 2K by throttling the vent valve. It has two 20 cm diameter openings, one on each end, to allow two separate science instruments to be mounted. Shielded low conductivity wirings are routed through the dewar vacuum space, while high current leads and coaxial cables are routed through the vent line tubing to allow for better heat exchange with the vent gas.

Electronics Capabilities

The electronics consist of three main assemblies each housed in a separate VME box with its own single board computer. The Facility Electronic Assembly controls the function of the dewar and handles communication with the JEM-EF. It provides housekeeping data on various parts of the dewar, controls the vent valves of the two instruments and provides throttling control of the dewar vent to control its temperature. In addition, it provides environmental data on charged particle radiation and acceleration by interfacing with an onboard charged particle monitor and a Space Acceleration Measurement System (SAMS) accelerometer provided by GRC. The two Experiment Electronic Assemblies each controls one science instrument. Capability for temperature control using germanium resistance thermometers is provided. Although the requirement is - $10\mu K/\sqrt{Hz}$ with $100nW$ of power through a resistance of $10K\Omega$, a prototype already exists with a resolution of better than $4\mu K/\sqrt{Hz}$ using $10nW$ of power. DC SQUID magnetometers will also be provided as part of the instrument electronic capability for interfacing with high-resolution thermometers, high-resolution pressure gauges and other sensitive magnetic transducers. The requirement for the SQUID noise is $30\mu\phi_o/\sqrt{Hz}$ compared to commercial units with noise of $5\mu\phi_o/\sqrt{Hz}$. The lower noise of the commercial unit is not required for the high-resolution thermometer readout, since the noise is dominated by noise from the sensor, not from the SQUID electronics. Heater drivers are also provided for temperature control and for delivering precision pulses of heat. There are spare slots for Investigators to design and build custom electronics boards unique to their experiment. All boards must conform to the VME64 standard with a 6U form factor and run with VxWork real time operating system.

Aside from these three boxes, there is a battery-pack, a baro-switch, and a circuit to autonomously open the dewar vent valve during ascent to allow the dewar to vent into space once it reaches high altitudes.

Probe Design and Capabilities

Each science instrument is 20 cm diameter and 45 cm long. The two instruments together can dissipate a total of 8 mW of power into the dewar tank. The Probe interfaces the science instrument package to the dewar. The probe's main functions are to provide mechanical support, thermal isolation and magnetic shielding. The components providing these capabilities are discussed briefly below:

Vacuum Can and the Adsorption Pump

The Vacuum Can maintains a high vacuum for thermal isolation purpose. As long as the vacuum can is leak tight against the surrounding helium in the dewar, maintaining high vacuum should not be a problem, since all gases except helium freeze. However, it has been found in previous flights that the science instrument package can heat up to close to 10K under the strong vibration of the launch if the instrument was under vacuum. During these previous launches, it was necessary to fill the vacuum can with ^{3}He-exchange gas to conduct the heat away from the science instrument to prevent it from heating up. Once on orbit, the exchange gas was vented to space and an adsorption pump, with activated charcoal, was used to absorb the rest of the gas. We inherited the adsorption pump design and modified it to make it lighter. The operation sequence is also inherited. The adsorption pump's design and operation are described in detail by Lysek et al[3].

Thermal Mechanical Structure

The thermal mechanical structure provides mechanical support and thermal isolation to the science instrument package. It consists of high strength and low thermal conductivity struts intercepted by thermal isolation stages made of high thermal conductivity material. It is designed to support 8 Kg of mass during launch and provide enough thermal isolation for the inner most stage to be operating at sub-nano-Kelvin stability. Figure 2 shows a picture of one such structure made of stainless steel struts and aluminum thermal isolation stages. In tests, this structure survived 7.7 g rms random vibration while supporting a 6.2 Kg mass. Each thermal stage has also demonstrated an ability to intercept most of the heat variations from the previous stage, allowing only one part in 7000 to leak through to the next stage. With 3 stages, this is more than enough to allow thermal control to sub-nano-Kelvin stability.

The resonance frequency of the structure together with the supported mass is an important parameter in mitigating the launch-heating problem. It was successfully demonstrated by Cui et al[4] that if this resonance frequency is sufficiently higher than the resonance frequency of the dewar, there is very little launch-heating. This implies that most of the heating arises from the flexing of the mechanical members of the instrument package. During testing, the structure shown in Figure 2 and discussed above had a resonance of 72 Hz compared with the 48 Hz resonance expected of the dewar. Thus we expect some mitigation of launch heating from this structure.

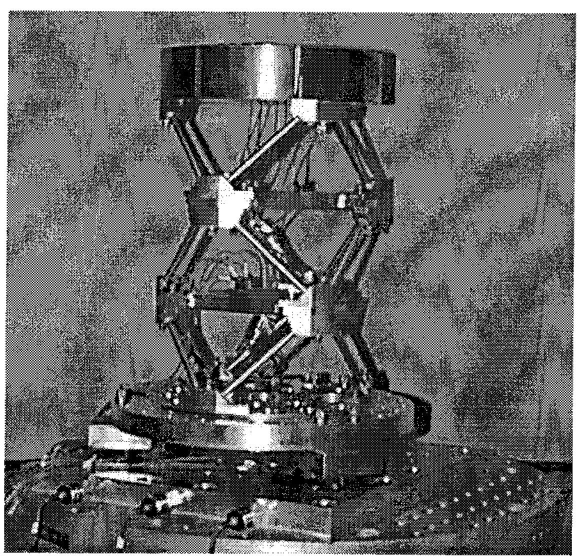

Figure 2: A picture of the thermal mechanical structure.

Magnetic Shields

Due to the high sensitivity of SQUIDs to magnetic fields, SUIDs are is usually operated inside a dewar with an external magnetic shield. This type of magnetic shield is heavy, weighing perhaps as much as 30 Kg. A way to reduce weight is to locate the shield outside the vacuum can instead. The shield is being developed and will be made of a special magnetic material – Cryoperm[4] 10, which is known to have permeability of 50,000 at low temperatures. It is expected to weigh less than 6 Kg and provides a magnetic environment with less than 10 mGauss of field variation inside.

Conclusion

The LTMPEF currently under development will provide a unique environment of low temperature and microgravity for long duration not. When the facility is launched in late 2005, it will open up exciting new science investigation opportunities onboard the International Space Station. JPL will provide the necessary infrastructure and service to enable a user-friendly interface to the scientific community, making easy and low cost access to space a reality for scientists.

Acknowledgements

This work is being carried out at the Jet Propulsion Laboratory, California Institute of Technology under contract to the National Aeronautics and Space Administration. The work was funded by NASA's Office of Biological and Physical Research, Physical Sciences Division. We thank BATC for providing the picture in Figure 1.

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